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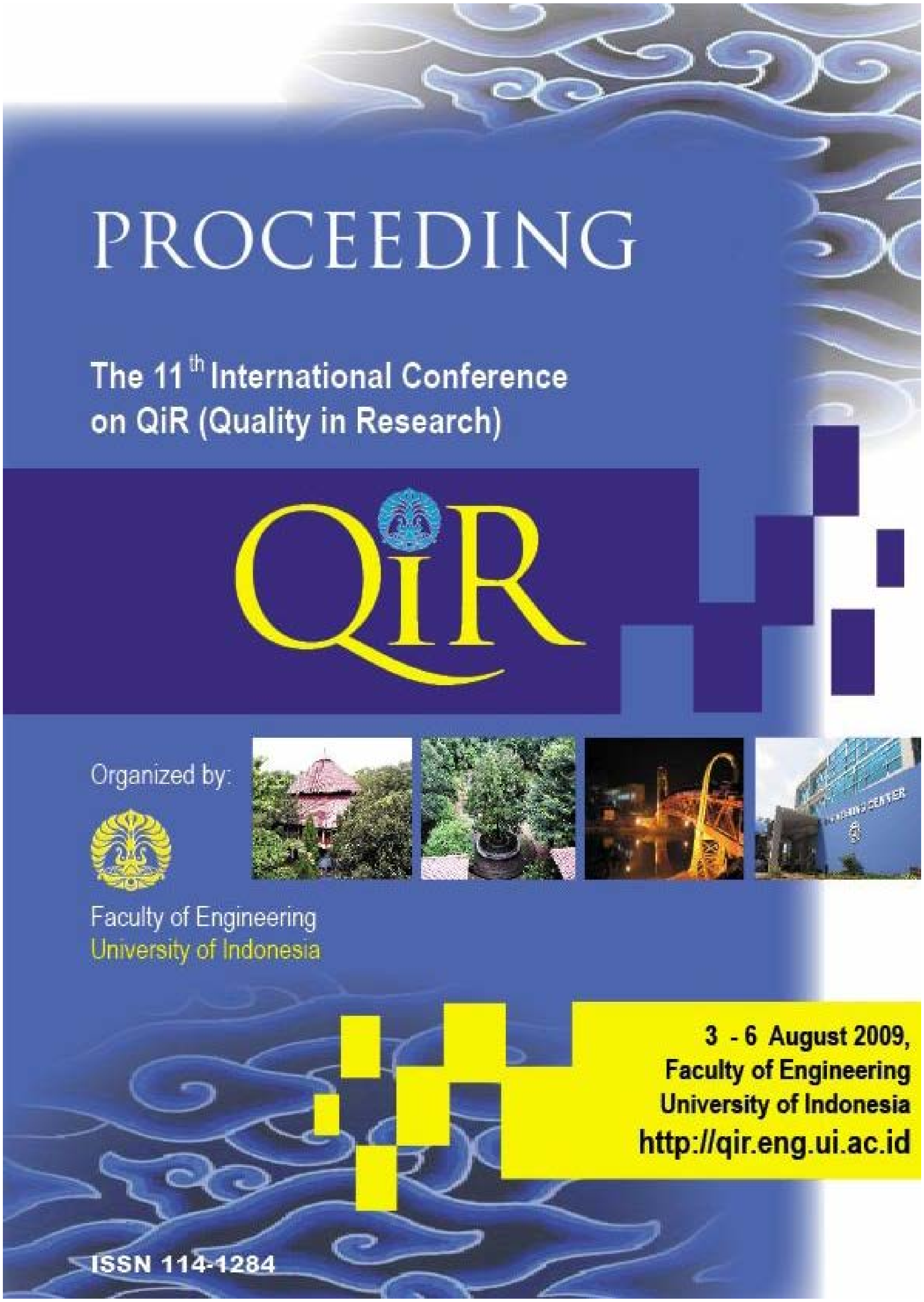

PROCEEDING

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A2-S3-3 CHAIRUL GAGARIN IRIANTO - PERFORMANCE ANALYSIS OF DELTA-ZIGZAG (DZ) CONNECTION TRANSFORMER

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A2-S3-5 HERAWATI - PERFORMANCE OF TOROID CORE PERMANENT

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Simulation of Flux Distribution and Loss Calculation at Three-Phase Three Limbs of Transformer Core with 23° T-Joint

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ABSTRACT

This paper describes the result of simulation of flux distribution on 100kVA 3phase distribution transformer assembled with 23° T-joint and mitred lap corner joint with stagger yoke and limb for one lamination. The simulation involves the variation of flux. The flux distributions have been simulated using 2DFEM by Quickfield Software built from M5 (CGO) grades material of transformer core laminations. The flux density is 1.78 T maximum at the centre limb of transformer core and the loss calculation is 1.274 W/kg.

Keywords
Grain oriented silicon iron, transformer core, 2DFEM, power loss calculation.

1. INTRODUCTION

The electrical transformer was invented by an American electrical engineer, William Stanley, in 1885 and was used in the first ac lighting installation at Great Barrington, Massachusetts. The first transformer was used to step up the power from 500 to 3000 V and transmitted for a distance of 1219 m (4000 ft). At the receiving end the voltage was stepped down to 500 V to street power and office lighting. By comparison, present transformers are designed to transmit hundreds of megawatts of power at voltages of 700 kV and beyond for distances of several hundred miles. [1]
Loss evaluation has become important because of high energy cost. Therefore, it is necessary to know in detail the behaviours of flux in transformer in order to develop cores with higher efficiency.

The efficient operation of power transformer cores depends to a large extent on the design of the joints between their limbs and yokes. In the three-phase, three limb core the most complex joints are the T-joints at the intersection the centre limb and yokes.[5]

The quantitative analysis of localized flux and loss distributions has become easier through the remarkable progress of numerical field calculations such as the finite element method. The numerical simulation is more effective and economical than experimental method. Moreover, useful suggestions for improving transformer can be obtained from the calculated flux and loss distribution

The objective of this simulation is to know the flux distribution and calculate the losses occur on the transformer core with 23° T-joint built from M5 grade material using 2D FEM.

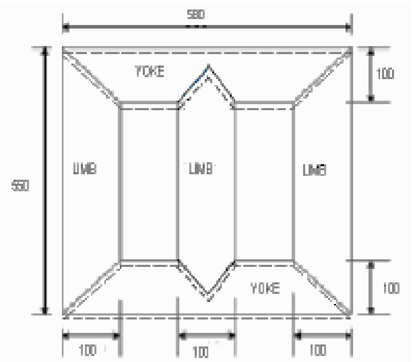

Figure 1: Dimension (mm) of 100kVA transformer model

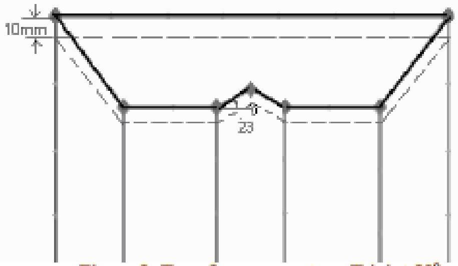

Figure 2: Transformer core type T-joint 23°

The localized flux density distribution in individual laminations is measured using search coils. The samples are drilled with an aid of drilling machine. It is constructed from 0.15 mm diameter wire treaded through 0.8 mm diameter holes 10 mm a part as shown in Figure 3. Each measuring position suitable coils are wound to measure the easy and hard direction flux density. The search coil induced voltages are analysed to find the magnitude and plane coil induced voltage of flux density by using power analyzer [PM6000] as shown in Figure 4.

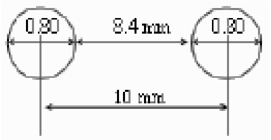

Figure 3: Dimensions [mm] of the holes drilled in the specimen

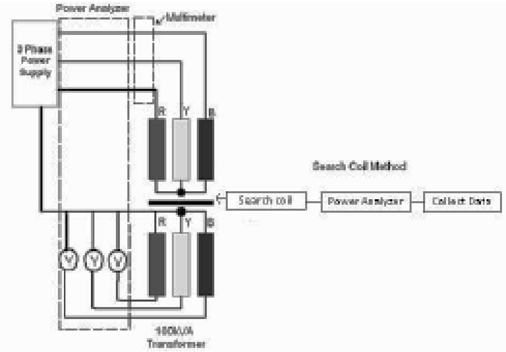

Figure 4: The diagram of the methods that used to measure the localised flux density.

The magnitude and direction with reference to the x axis of the in-plane instantaneous flux density can be written in the form [3]:

$$|b| = \frac{1}{4fNAn}[\bar{e}_x{}^2 + \bar{e}_y{}^2]^{1/2} \qquad (1)$$

And

$$\alpha = \tan^{-1}\left(\frac{e_y}{e_x}\right) \qquad (2)$$

Where
f = frequency supply
N = Number of transformer winding
A = Cross section area of transformer core lamination that measured
n = number of layer of transformer core lamination
e_x = maximum value of the component of induced emf in the easy direction
e_y = maximum value of the component of induced emf in the hard direction

Sample calculation as follow:
From transformer frame are obtain number of turn is 254 turns, area of lamination is 0.000003m^2 with number of layer is 15 layers and frequency supply is 50 Hz. When the supply adjusted to transformer at 1.5T so at the search coil will find the induced emf by oscilloscope measurements at easy direction is 190mV and hard direction is 180mV. By using the equation (1) will find the flux density at this point is 103mT.

The primary induced emfs in the windings of the three phase transformers core were monitored by three identical voltmeters and voltages displayed during the measurement were only allowed to vary well within ± 0.4% of the induced voltage corresponding to the required flux density.

Flux distribution in the Cold Rolled Grain Oriented (CRGO) is measured by using an array of search coils to get the satisfactory result. In this investigation an array of single turn search coil is employed to measure in-plane (longitudinal and transverse) of flux density in the lamination within the transformer core as indicated in figure 5.Because the flux tends to deviate out of the longitudinal direction in some region, small 10mm search coils are used to measure localized longitudinal and transverse flux component. The locations are chosen to cover the areas where the flux is more likely to vary direction so as to find distribution of the flux behavior as shown in Figure 5.

The testing process is done by using the No-Load Test Frame. The No-Load Test Frame consisting of three windings for each three phase core are designed in order not only to avoid introducing stress to the laminations but also to keep the magnetism exactly constant in all limbs of the cores. Each winding only extends along 85% on each limb in order to enable the stagger length of the three phase core to be varied. An extra softwood base 200mm high is used to raise the overall height of the core, in order to minimize the effect of the stray flux on the localized measurements.

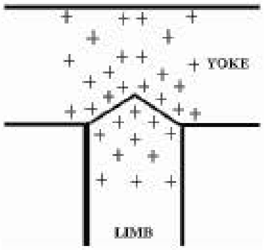

Figure 5: Location of orthogonal search coils in the three phase core.

Installation search coil takes quite a long time in completing this step which every hole needs to be inserted with search coil. Search coil is the enamel copper coated 0.1mm diameter wire. Each set of test point (4 holes) consist of easy and hard direction where the holes of easy and hard direction will be inserted search coil and the leads are twisted together. All the holes at testing point need to be repeated the same method of inserting and twisting the leads.

After the search coils are wound and the leads twisted together, the holes are filled with polyurethane varnish to give added insulation protection. The search coil leads, which are twisted to prevent any spurious pick up, are stuck to the lamination by a polyurethane varnish. The leads from all the search coils are taken to a junction box placed in the core to prevent any interference from the core or magnetising windings.

3. RESULTS AND DISCUSSION

The instantaneous magnitude and direction of flux at this instant is shown in Figure 6 on a larger scale. At this instant the total flux in the centre limb reaches its maximum and outer limb carry half their maximum flux. A small amount of flux deviation from the rolling direction occurs at the overlap.

The rotational flux produced in the T-joint region of the three-phase three limbs transformer core are due to a combined effect of alternating and rotating fields. This rotational flux illustrates the locus of the variation of the variation of the localized flux distribution throughout the magnetizing cycle. The rotational flux of the fundamental component (50Hz) of flux density in the 10mm staggered core at a core flux density of 1.5T is shown in Figure 7. A large rotational flux is present in the yoke area which near with centre limb. Rotational flux in this region is more circular. Some large rotational flux is also observed in or near the T-joint region.

Figure 8 shows the rotational flux of the third harmonic component of flux density in the T-joint of the core assembled with 23^0 at core flux density of 1.5T. The extent of rotating flux at this frequency is more widespread. As with the 50Hz component, a large amount of rotating flux is present in the T-joint region between the right yoke and centre limb in all four cores. A small rotating flux occurs also observed in the middle of centre limb region in all four cores. There is more rotational flux present in this region.

The major axes of the locus do not always follow those of the fundamental component (particularly the 23^0 T-joint of core) but tend to be parallel to butt joints over much of the core where the fundamental components also deviate from the longitudinal direction of the strip in the yoke.

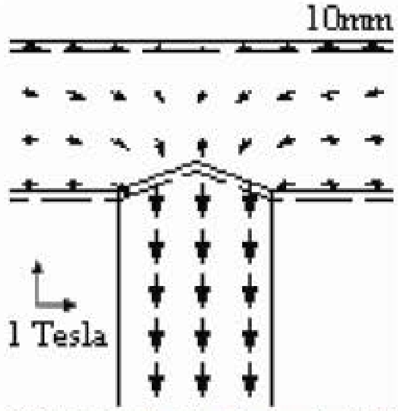

Figure 6: Distribution of localized flux density at 23^0 T-joint

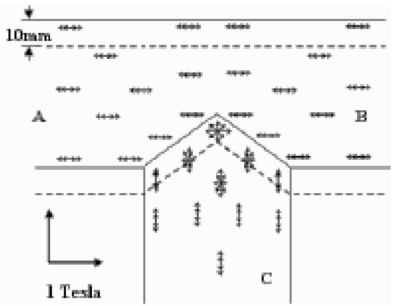

Figure 7: Locus of the fundamental component of localised flux density in 23^0 T-joint staggered core with overlap length 10 mm at 1.5T, 50Hz

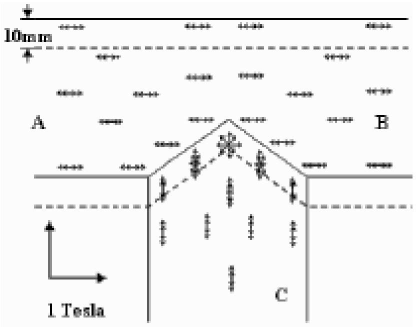

Figure 8: Locus of the third harmonic component of localised flux density in 23^0 T-joint staggered Core with overlap length 10 mm at 1.5T, 50Hz.

Figure 9 shows that the rotational flux of the fifth harmonic component of flux density in the T-joint of the core assembled with 23^0 at core flux density of 1.5T is more widespread. The magnitude of the rotational flux is small compared with that of the fundamental and third harmonic. The distribution of the fifth harmonic component is classified to a region near to and within the T-joint.

A large amount of rotating flux is present in the T-joint region between the right yoke and centre limb in the core. Rotating flux in this region is elliptical with the 23^0 T-joint of core showing the highest value. A small rotating flux occurs also observed in the middle of centre limb region in the core.

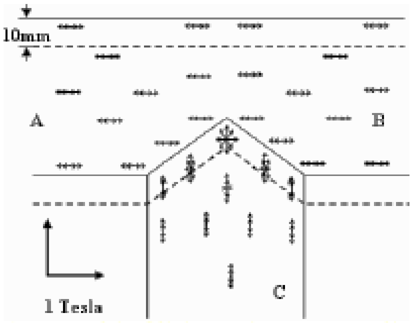

Figure 9: Locus of the fifth harmonic component of localised flux density in 23^0 T-joint staggered cores with overlap length 10 mm at 1.5T, 50Hz

Figure 10 shows the measuring point of location and localized flux densities at 23° T-joint that are measured by using the search coil on transformer core. This result is produced by calculating localized flux density after the search coil measures the vector of the voltage in the easy and hard direction at the lamination.

The flux density in the yoke then drops rapidly as the flux distributes itself equally between the laminations. The flux density reaches a peak at the inner of 23° T-joint; this is caused by the saturated material. The minimum flux density occurs at the outer of 23° T-joint of transformer core lamination. The localised flux density will increase from the outer to the inner edge of the 23° T-joint. The localised flux density at the outer 23° T-joint is 0.190T and rises to be 0.217T at the inner edges of yoke at 23° T-joint when the transformer core energized 1.5 T 50Hz.

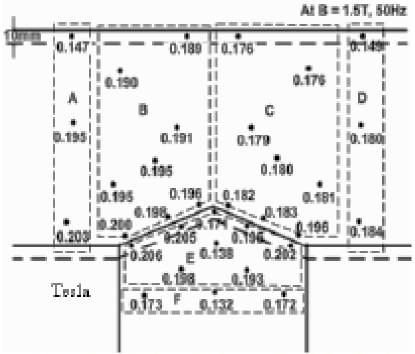

Figure 10: Local variations in the Tesla of the fundamental peak in-plane flux density of the lamination in 23^0 T-joint of three phase staggered core with overlap length 10 mm at 1.5T, 50Hz.

The local variation in magnitude of the third harmonic component of peak in-plane flux density in the 23° T-joint at a core flux density of 1.5T is shown in Figure 11. Most of the high third harmonic flux occurs in the T-joint region. The high third harmonic of peak in-plane flux occurs at the inner edge of right yoke passes over to the Butt-joint of centre limb is 23.4mT. Harmonic occurs mostly in the T-joint where local regions are saturated and the flux deviates from the rolling direction. However, it has been confirmed experimentally that harmonics circulated in individual laminations in the limbs and yokes.

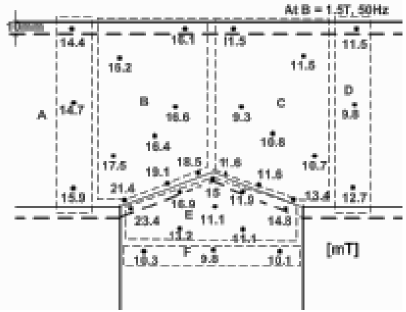

Figure 11 Local variations in the mT of the third harmonic peak flux density to the fundamental component in-plane of the lamination in 23^0 T-joint of three phase staggered core with overlap length 10 mm at 1.5T, 50Hz.

The local variation in magnitude of the fifth harmonic component of peak in-plane flux density in the 90° T-joint at a core flux density of 1.5T is shown in Figure 12 to be very small.

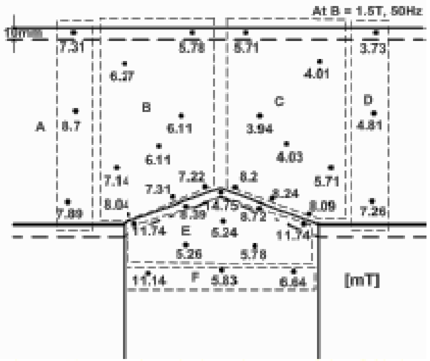

Figure 12: Local variations in mT of the fifth harmonic peak flux density to the fundamental component in-plane of the lamination in different T-joint of three phase staggered core with overlap length 10 mm at 1.5T, 50Hz.

4. CONCLUSION

The flux distribution in cores assembled with M5 material was found varies along overlap area of the stagger at the T-joint. The localised in-plane flux density will increase from the outer to the inner of the 23° T-joint. The localised flux density at the outer edges 23° T-joint is 0.147T and rises to be 0.206T at the inner edges of 23° T-joint when the transformer core energized 1.5 T 50Hz. A large rotational flux is present in the yoke area which near with centre limb. Rotational flux in this region is more circular.

The high third harmonic of peak in-plane flux occurs at the inner edge of right yoke passes over to the Butt-joint of centre limb is 22.2mT.Harmonic occurs mostly in the T-joint where local regions are saturated and the flux deviates from the rolling direction.
A small amount of flux deviation from the rolling direction occurs at the overlap, but no rotational flux is present in the joint.

The local variation in magnitude of the fifth harmonic component of peak in-plane flux density in the 23° T-joint at a core flux density of 1.5T is to be very small

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REFERENCES

[1] Jones, A. J., Moses, A. J., Comparison of the Localized Power Loss and Flux Distribution in the Butt and Lap and Mitred Overlap Corner Configurations, *IEEE Tans. ON MAG.*, VOL. MAG-10, No. 2, june 1974.
[2] Mansel A Jones and Antony J. Moses, Comparison of the Localized Power Loss and Flux Distribution in the Butt and Lap and Mitre Overlap Corner Configurations, *IEEE Trans. On Mag.*, Vol, MAG-10, No.2, June 1974
[3] Daut, I and Moses, A.J., Some Effects Of Core Building On Localised Losses And Flux Distribution In A Three-Phase Transformer Core Assembled From Powercore Strip, *IEEE Trans. On Mag.*, Vol. MAG-26, No 5, pp. 2002, Sept 1990
[4] Daut, I,"*Investigation of Flux and Loss Distribution in Transformer Cores Assembled From Amorphous Powercore Material*", 1992, PhD Thesis University of Wales
[5] Beckley P., *Electrical Steels for rotating machines*, The Institution of Electrical Engineers, 2002.
[6] Indrajit Dasgupta, *Design of Transformers Handbook*, Tata Mc-Graw Hill, India, 2002.
[7] James H. Harlow, *Electric Power Transformer Engineering*, CRC Press LLC, 2004.

[8] Daut I, Dina M.M. Ahmad and S. Taib, *Measurement of flux distribution on 100kVA 3phase distribution transformer assembled with 60° T-joint and mitred lap corner joint with stagger yoke by using search coil*, MUCET2008 8th-10th March 2008, Hotel Putra Palace, Perlis, Malaysia.

[9] Daut, Dina M.M. Ahmad, and S. Taib , *Measurement of Flux Distribution on 100kVA 3phase Distribution Transformer Assembled With 45° T-Joint And Mitred Lap Corner Joint With Stagger Yoke By Using Search Coil*, IASTED AsiaPES2008, 2nd-4th April 2008, Meritus Pelangi Beach Resort Hotel, Langkawi, Malaysia, ISBN CD: 978-088986-732-1

[10] Daut, Dina M.M. Ahmad, and S. Taib , *Comparison Between The Localized Power Loss and Flux Distribution in a Three Phase Distribution Transformer 100 kVA Assembled From Various Type of T-Joint Geometry with Staggered Yoke*, IASTED AsiaPES2008, 2nd-4th April 2008, Meritus Pelangi Beach Resort Hotel, Langkawi, Malaysia, ISBN CD: 978-088986-732-1,

[11] Dina M.M. Ahmad, Ismail Daut, *Measurement of Flux Distribution on 100kVA 3phase Distribution Transformer Assembled With 23° T-Joint and Mitred Lap Corner Joint with Stagger Yoke by Using Search Coil*, The 2ndInternational Power Engineering and Optimization Conference (PEOCO2008), Shah Alam, Selangor, MALAYSIA. 4-5 June 2008.

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The Localized Loss on 100kVA 3-Phase Distribution Transformer assembled with 23° T-joint

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ABSTRACT

This paper describes the result of measurement of localized loss distribution on 100kVA 3phase distribution transformer assembled with 23° T-joint and mitred lap corner joint with staggered yoke. The measurement involves the variation of temperature rise. The localized loss have been measured using no load test by arrays of thermistor on the surface of M5 (CGO) grades material of transformer core laminations. The localised loss at the outer 23° T-joint is 1.05 W/kg and rises to be 1.26 W/kg at the inner 23° T-joint when the transformer core energized 1.5 T 50Hz. The several harmful effects can occur because the flux flows out of the rolling direction.

Keywords
Grain oriented silicon iron, transformer core ,temperature rise, power loss..

1. INTRODUCTION

An important factor in the design of the T-joint in three limbs, three-phase power transformers is the localized loss variation within the joint. Not only is the overall loss of the core affected by the T-joint, but high localized losses can generate hot spots in the core. The power-loss distribution depends upon the localized flux density variation, which in turn depends on the design of the joint. A particular joint configuration might produce rotational flux, normal flux between layers of laminations, or alternating flux directed away from the rolling direction of the laminations, all of which tend to increase the core loss. [1]

The objective of this investigation is to obtain the localised loss distribution of the transformer core built from electrical steel (M5) with 3% silicon iron assembled with 23° T-joint and mitred lap corner joint with stagger yoke by using thermistor.

2. EXPERIMENT APPARATUS AND MEASURING TECHNIQUES

A 3-phase,3 limb stacked cores are assembled with 23° T-joint and mitred lap corner joints as indicated in Figure 1.The core is 550 mm x 580 mm with the limbs and yokes 100 mm wide. The core is assembled from 0.3 mm thick laminations of M5 grain-oriented silicon iron (CGO) as indicated in Figure 2 and the core comprises of 15 layers has staggered yoke of core with overlap length of 5 mm from other adjacent lamination. Staggering alternate layers of laminations in the yoke direction as indicated in figure 2 is known to reduce the losses of core assembled from silicon iron [2]

Localised loss on the Cold Rolled Grain Oriented (CRGO) is measured by using an array of thermistor to get the satisfactory result. The locations chosen must cover the areas where the loss is more likely to vary direction so as to find distribution of the flux behavior as shown in Figure 3.

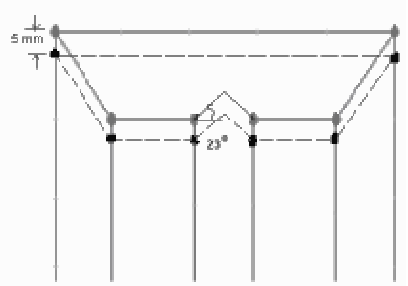

Figure 1: Transformer core type with T-joint 23°

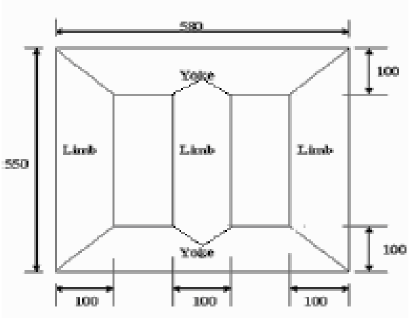

Figure 2: Dimension (mm) of 100kVA transformer model

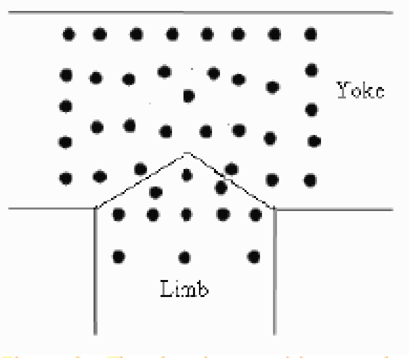

Figure 3: The thermistor position on the T-joint of transformer core

The testing process is done by using the No-Load Test Frame. The No-Load Test Frame consisting of three windings for each three phase core are designed in order not only to avoid introducing stress to the laminations but also to keep the magnetism exactly constant in all limbs of the cores as indicated in figure 4. The core could be energized to 1.5 T (50Hz)

Loss will be obtained by calculating the multiple of gradient temperature on the lamination to relationship constant of gradient temperature and power loss reference. The power loss reference is obtained by using Epstein Test measurement with comparison temperature rise in the the middle of the limb of core lamination and nominal loss at adjusted 1.5T, 50Hz.

The relationship between loss and temperature rise will be found from the equation as follows:

$$P_{loss} = C\, {}^{dT}\!/_{dt} \qquad (1)$$

where C is the relationship constant that is C = 14 [W-minutes/kg-°C]

${}^{dT}\!/_{dt}$ is temperature rise from measurement

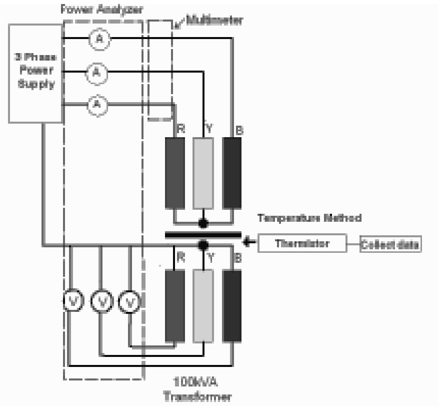

Figure 4: The diagram of the methods that is used to measure the localised temperature rise

3. RESULTS AND DISCUSSION

Figure 5 shows the mesh graph of the localised loss measured by using the thermistor at the 23° T-joint of transformer core lamination. This mesh graph is drawn by using the Matlab software based on the result of this investigation. The power loss at 23° T-joint shows that the power loss reaches a peak at the inner edge of 23° T-joint and the minimum power loss occurs at the outer edge of 23° T-joint of transformer core lamination. The localised power loss will increase from the outer edge to the inner edge of the 23° T-joint. The localised power loss at the outer edge of 23° T-joint is 1.05 W/kg and rise to be 1.26 W/kg at the inner edge of 23° T-joint when the transformer core energized 1.5 T 50Hz. The major regions where the flux deviates from the rolling direction are at the 23° T-joint where the flux passes from the yoke to the limbs. Here several harmful effects can occur because the flux flows out of the rolling direction.

Figure 6 shows the measuring point of location and localised power loss that are measured by using thermistor at 23° T-joint. This result is produced by calculating the multiple of temperature rise on the lamination to relationship constant of temperature rise and power loss reference.

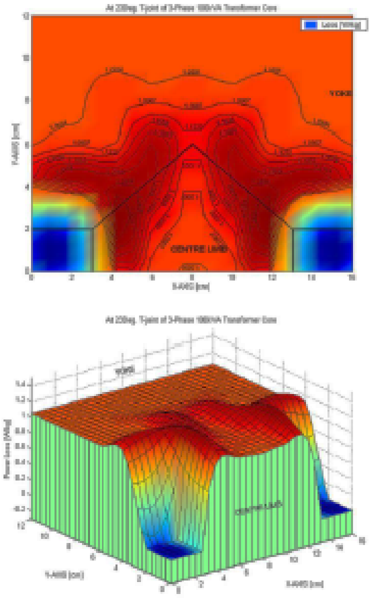

Figure 5: The mesh graph of the localised loss measured by the temperature method at the 23° T-joint.

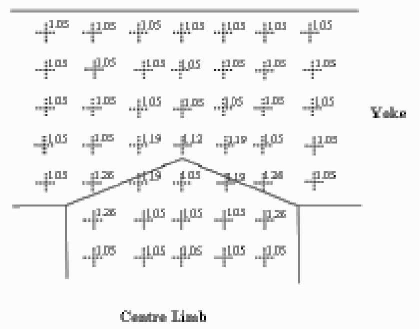

Figure 6: The average localized power loss at 23° T-joint (the values are expressed in W/kg) is measured by using temperature method.

4. CONCLUSION

The localised loss distribution on cores assembled with M5 materials varies along overlap length of 23° T-joint of core laminations. The localised power loss will increase from the outer edge to the inner edge of the 23° T-joint. The localised power loss at the outer edge of 23° T-joint is 1.05 W/kg and rise to be 1.26 W/kg at the inner edge of 23° T-joint when the transformer core energized 1.5 T 50Hz. The T-joint of core lamination occur several harmful effects caused by the flux flows out of the rolling direction.

ACKNOWLEDGMENT

The authors would like to express their gratitude to the Malaysian Transformer Manufacturing (MTM) for the supply of transformer core material.

REFERENCES

[1] Anthony j. Moses and bleddeyn Thomas, The Spatial Variation of Localized Power Loss in Two Practical Transformer T-Joints, *IEEE Trans. On Mag., VOL. MAG-9*, no. 4, december 1973
[2] Daut, I and Moses, A.J., Some Effects Of Core Building On Localised Losses And Flux Distribution In A Three-Phase Transformer Core Assembled From Powercore Strip, *IEEE Trans. On Mag., Vol. MAG-26*, No 5, pp. 2002, Sept 1990
[3] Daut, I,"*Investigation of Flux and Loss Distribution in Transformer Cores Assembled From Amorphous Powercore Material*", 1992, PhD Thesis University of Wales
[4] Beckley P., *Electrical Steels for rotating machines*, The Institution of Electrical Engineers, 2002.
[5] Indrajit Dasgupta, *Design of Transformers Handbook*, Tata McGraw Hill, India, 2002.
[6] James H. Harlow, *Electric Power Transformer Engineering*, CRC Press LLC, 2004.

Normal Flux Distribution in 23° T-joint of Three Phase Transformer Core with Staggered Yoke 10mm

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ABSTRACT

This paper describes the result of an investigation in 3-phase 100kVA transformer core assembled with staggered yoke of 10mmoverlap length. The investigation involves the variation of normal flux distribution in the core lamination. The normal flux distribution has been measured at T-joint core model of 15 layers of lamination by arrays of search coil. The highest normal flux distribution occurs at the upper edge of the middle limb that is 0.170T and lowest at upper edge of yoke that is 0.1T. The average value of normal flux distribution is high at flux transfer region of the lamination. The flux transfer mechanism shows that two separate path flowing horizontally in the yoke before leaving the lamination to vertically adjacent layer and combine with the flux in that layer. The Fluxs will drops in the T-joint are approached as flux diverts to adjacent laminations above and below to avoid the high reluctance air gap.

Keywords: *Grain oriented silicon iron, transformer core, normal flux distribution, fundamental flux.*

1. INTRODUCTION

Power transformers are usually employed in electric power stations, high voltage transmission lines and large utilities. On the other hand, distribution transformers can be found in small and midsize industries, hotels, hospitals, schools, entertainment centers, residential areas and etc [1].

Transformers are ubiquitous in all part of the power system, between all voltage levels, and exist in many different sizes, types and connections [2]. Grain-oriented 3% silicon-iron is used for transformer cores where high efficiency and low weight are often paramount [3]. The efficient operations of power transformer cores depend on a large extend on the design of the joints between their limbs and yokes. The most complex joint in three limb cores are the T-joints at the intersection of the centre limb and yokes. Under ideal conditions the total flux in the limbs of a transformer core has a sinusoidal waveform, but in the corners of the core the flux is far from sinusoidal. The additional loss caused by the flux distortion can lead to localized heating within the joints [4].

The objective of this research is to measure normal flux distribution on the lamination of transformer core that built from the electrical steel (M5 grade material) 3% silicon-iron assembled with 23° T-joint mitred lap corner joint with staggered yoke by using array of search coils.

2. EXPERIMENT APPARATUS AND MEASURING TECHNIQUES

Three phase 100kVA distribution transformers are assembled with 23° T-joint, mitred overlap corner joints length of 10mm as indicated in figure 1. Each core is 550 mm x 580 mm with the limbs and yokes 100 mm wide as indicated in figure 2. The main apparatus consisted of three phase cores, two yoke cores and three limbed cores and the cores are assembled from 0.3 mm thick laminations of M5 grain oriented silicon iron (CRGO) [7]. Each core comprises of 15 layers. The system for measuring normal flux density is shown in Figure 3.

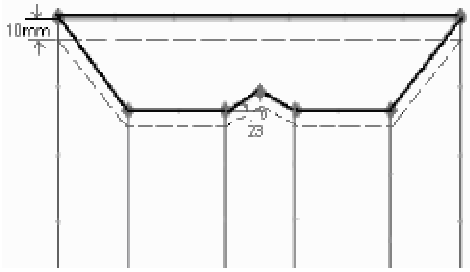

Figure 1: 23° T-joint transformer core type with staggered yoke 10mm

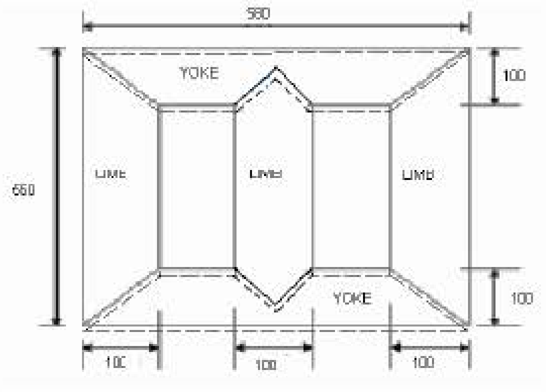

Figure 2: Dimension (mm) of 23° T-joint 100kVA transformer model

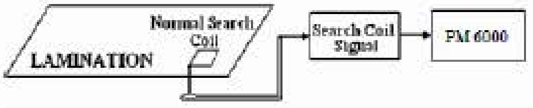

Figure 3: Associated system for measuring normal flux density.

In order to study the normal flux density variation, normal search coil arrays are used to measure normal flux density variation along and across the lamination. The squares of 10mm x 10mm normal search coils are placed on a layer of lamination at the T-joint of the transformer core. The locations chosen must cover the areas where the flux is more likely to vary direction so as to find the mechanism distribution of the flux behavior. The location of the investigation for the transformer core is shown in figure 4.

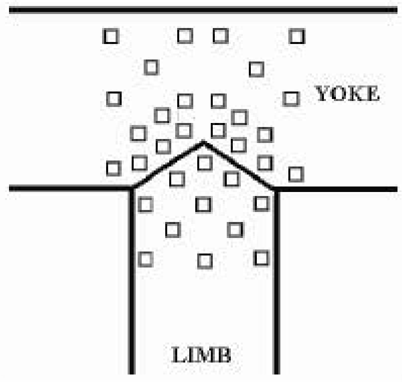

Figure 4: The normal search coils position in the T-joint of transformer core

3. RESULTS AND DISCUSSION

Fundamental normal flux density at T-joint flowing in a direction normal to the plane of the lamination in the staggered yoke 10mm 1.5T, 50Hz is shown in figure 5.

The magnitude of the normal flux density is high at and close to an intersection between two adjacent laminations. The highest normal flux occurs at the corner edges of centre limb that is 0.170T at flux density 1.5T, 50Hz. The average magnitude of normal flux density is largest at the overlap region and smallest at the upper edge of the right yoke. The fundamental normal flux density increases as it approaches the T-joint and gradually decrease as it travels further away from the joint. The magnitude of fundamental normal flux density traveling between joints reaches minimum at the mid point of centre limb. This alteration in the fundamental normal flux density is due to increase and decrease of flux density that has been energized.

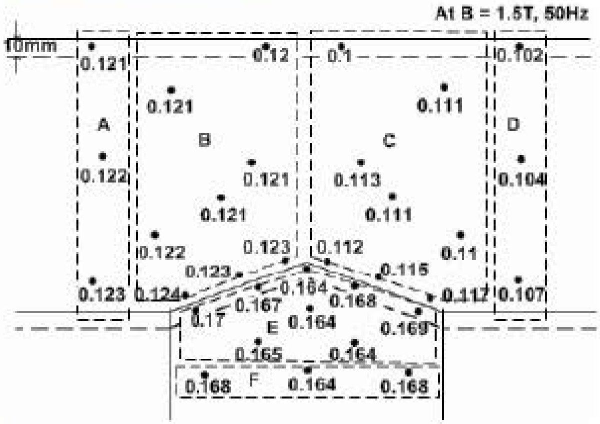

Figure 5: Distribution of the normal direction of fundamental flux density at T-joint with overlap length of 10mm during 1.5 at 50Hz.

The instantaneous magnitude and direction of flux at this instant is shown in figure 6 at this instant the total flux in the centre limb reaches its maximum and both right and left yoke carry half their maximum flux.

Since the yokes carry only half the maximum value of the total flux, the majority of the flux from the outer of right and left yoke is carried through the inner half of junction of middle limb and the largest flux concentration is found in the upper edges of middle limb.

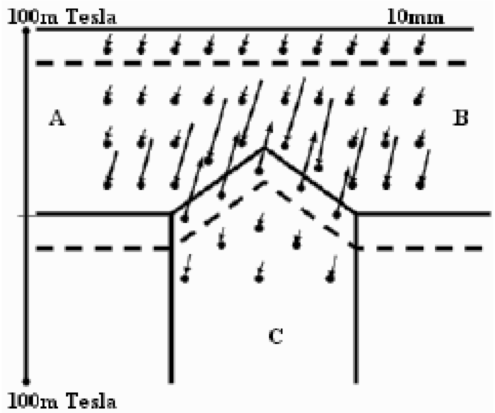

Figure 6: Distribution of the fundamental component of localised normal flux density in the 23 ° T-joint of three phase core built at different instant in time when ωt=60°.

Flux path and flux transfer mechanism between laminations at the T-joint has been illustrated as figure 7 for staggered yoke arrangement. The diagram shows that the flux transfer mechanism between yoke and limb in the T-joint may occur simultaneously at the same instant in time. This can be seen for example at the A and B region where two separate path flowing horizontally before leaving the lamination to vertically adjacent layer of D and F respectively and combines with the flux in that layer. Consequently, the core material in this region approaches saturation. At the same time, this existing flux will transfer back to the C region and extend to the whole length of the middle limb. It has been noticed that the magnitude of normal flux density high at the inner edges of yoke at junction between yoke and middle limb and decrease as the distance away from the joint.

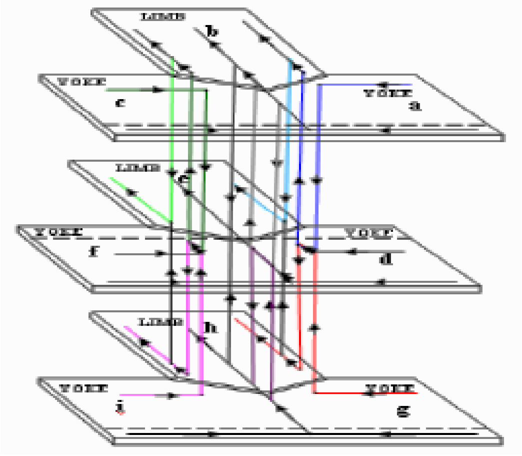

Fig. 7: Flux transfer between laminations of staggered yoke limb arrangement at the T-joint.

3. CONCLUSION

From the result of this investigation, the normal flux distribution in the cores assembled with 23°T-joint was found varies along overlap area of the staggered at the T-joint. High normal flux distributions occur in the corner edge of the centre limb that is 0.170T and gradually decrease as it travels far away from the joint area.

The flux transfer mechanism between yoke and limb in the T-joint may occur simultaneously at the same instant in time. The flux transfer mechanism most occur at T-joint of the transformer core compared to the other places. The magnitude of normal flux density is high at nearest of the junction of T-joint and decrease as the distance away from the joint.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the Malaysian Transformer Manufacturing (MTM) for the supply of transformer core material.

REFERENCES

[1] C. Hernandez, M.A. Arjona, and Shi-Hai Dong, "Object-Oriented Knowledge-Based System for Transformer Design," *IEEE Transactions On Magnetics*, vol. Mag-44, No. 10, October 2008.

[2] O.A. Mohammed, Fellow, IEEE, N.Y. Abed and S. Liu, "Investigation of the Harmonic Behavior of Three Phase Transformer Under Nonsinusoidal Operation Using Finite Element and Wavelet Packets,"

[3] J. Moses, T. Meydan, and H. F. Lau, "Domain Structures in Silicon-Iron in the Stress Transition Stage," *IEEE Transactions On Magnetics*, vol. 31, No. 6, November 1995.

[4] Moses,A. J., B. Thomas, and J. E.Thompson, "Power Loss and Flux Density Distributions in the T-Joint of a Three Phase Transformer Core," *IEEE Transactions On Magnetics*, vol. Mag-8, No. 4, December 1972.

[5] Jones, A. J., Moses, A. J., Comparison of the Localized Power Loss and Flux Distribution in the Butt and Lap and Mitred Overlap Corner Configurations, *IEEE Tans. ON MAG., VOL. MAG-10*, No. 2, june 1974.

[6] Mansel A Jones and Antony J. Moses, Comparison of the Localized Power Loss and Flux Distribution in the Butt and Lap and Mitre Overlap Corner Configurations, *IEEE Trans. On Mag., Vol, MAG-10*, No.2, June 1974

[7] Daut, I and Moses, A.J., Some Effects Of Core Building On Localised Losses And Flux Distribution In A Three-Phase Transformer Core Assembled From Powercore Strip, *IEEE Trans. On Mag., Vol. MAG-26*, No 5, pp. 2002, Sept 1990

[8] Daut, I.,"*Investigation of Flux and Loss Distribution in Transformer Cores Assembled From Amorphous Powercore Material*", 1992, PhD Thesis University of Wales

[9] Beckley P., *Electrical Steels for rotating machines*, The Institution of Electrical Engineers, 2002.

[10] Indrajit Dasgupta, *Design of Transformers Handbook*, Tata Mc- Graw Hill, India, 2002.

[11] James H. Harlow, *Electric Power Transformer Engineering*, CRC Press LLC, 2004.

[12] Daut I., Dina M.M. Ahmad and S. Taib, *Measurement of flux distribution on 100kVA 3phase distribution transformer assembled with 60° T-joint and mitred lap corner joint with*

stagger yoke by using search coil, MUCET2008 8th-10th March 2008, Hotel Putra Palace, Perlis, Malaysia.

[13] Daut, Dina M.M. Ahmad, and S. Taib , *Measurement of Flux Distribution on 100kVA 3phase Distribution Transformer Assembled With* 45^o *T-Joint And Mitred Lap Corner Joint With Stagger Yoke By Using Search Coil,* IASTED AsiaPES2008, 2nd-4th April 2008, Meritus Pelangi Beach Resort Hotel, Langkawi, Malaysia, ISBN CD: 978-088986-732-1

[14] Daut, Dina M.M. Ahmad, and S. Taib , *Comparison Between The Localized Power Loss and Flux Distribution in a Three Phase Distribution Transformer 100 kVA Assembled From Various Type of T-Joint Geometry with Staggered Yoke*, IASTED AsiaPES2008, 2nd-4th April 2008, Meritus Pelangi Beach Resort Hotel, Langkawi, Malaysia, ISBN CD: 978-088986-732-1,

[15] Dina M.M. Ahmad, Ismail Daut, *Measurement of Flux Distribution on 100kVA 3phase Distribution Transformer Assembled With* 23^o *T-Joint and Mitred Lap Corner Joint with Stagger Yoke by Using Search Coil*, The 2ndInternational Power Engineering and Optimization Conference (PEOCO2008), Shah Alam, Selangor, MALAYSIA. 4-5 June 2008.

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In-plane Flux Distribution in 23° T-joint of 3Phase Transformer Core with Staggered Yoke 10mm

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ABSTRACT

This paper describes the result of measurement of in-plane flux distribution on 100kVA 3phase distribution transformer assembled with 23° T-joint and mitred lap corner joint with stagger yoke of 10mm. The measurement involves the fundamental, third and fifth harmonic of the easy and hard direction of flux density at each location measurement. The flux distributions have been measured using no load test by arrays of search coil in M5 (CGO) grades material of transformer core laminations. The localised flux density at the outer 23° T-joint is 0.147T and rises to be 0.206T at the inner edges of 23° T-joint when the transformer core energized 1.5 T 50Hz. Harmonic occurs mostly in the T-joint where local regions are saturated and the flux deviates from the rolling direction.A small amount of flux deviation from the rolling direction occurs at the overlap, but no rotational flux is present in the joint.

Keywords
Grain oriented silicon iron, transformer core, in-plane flux distribution.

1. INTRODUCTION

Transformer iron loss can be reduced either by improving the quality of the steel or by using better building and design techniques. The efficiency of a transformer core is also largely dependent upon the design of the joints at the junctions of the yoke and limbs. In these regions the flux may deviate from the rolling direction of the steel or become distorted so that local areas of the high loss are produced. [1] The use of grain-oriented silicon iron has been the main beneficial factor in increasing transformer efficiency. [2]

The behaviour of this investigation is to understand the in-plane flux distribution of the transformer core built from electrical steel (M5) with 3% silicon iron assembled with 23° T-joint and mitred lap corner joint with stagger yoke of 10mm by using arrays of search coil.

2. EXPERIMENT APPARATUS AND MEASURING TECHNIQUES

The main apparatus consist of a model cores three-phase 100kVA transformer assembled with three limbs core with T-joint cutting angle 23° assembled from CRGO (M5 grades) 3% Si-Fe material. The core has 550 mm x 580 mm with the limbs and yokes 100 mm wide as shown in Figure 1. The experimental cores assembled with T-joint 23°, mitred overlap corner joints with staggered yoke and overlap length is 10mm as shown in Figure 2 and assembled from 0.3 mm thick laminations of M5 grain-oriented silicon iron (CRGO). Associated instruments are used to measurement fundamental, third and fifth harmonic content of the localised flux density distribution.

2. METHODOLOGY

Methodology that is used to complete this investigation had been divided into three major tasks:

1. Drawing transformer core assemble with 23° T-Joint and M5 grade material
2. Simulation of the transformer core drawing
3. Loss calculation for the transformer core material

Drawing the transformer core configuration is the first step before doing the simulation. In this simulation, this drawing had been done using Quickfield v5.2 software. QuickField is an interactive environment for electromagnetic, thermal and stress analysis. In QuickField, it works with several types of documents: problems, geometry models, material libraries and others. QuickField can perform linear and nonlinear magnetostatic analysis for 2-D and asymmetric models. The program is based on a vector potential formulation.
Dimension of the 100kVA transformer core model are as figure 1. The configuration of T-Joint is drawing in Figure 2.

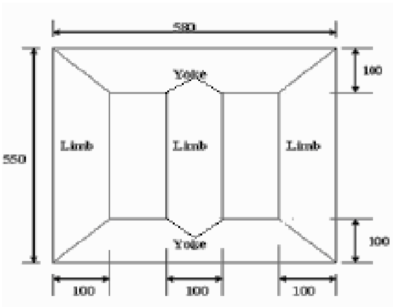

Figure 1: Dimension (mm) of 100kVA transformer core model

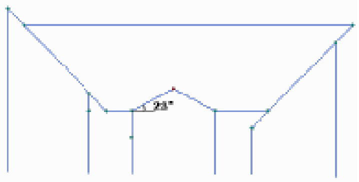

Figure 2 : Transformer core type 23° T-joint

To identify the material, B-H curve reading need to be tuck at the data column for each of the limb. The values for material can be obtained from the B-H curve. The data should be tucking as indicated in table 1.

Table 1: B-H curve data from the exciting force

Flux Density [T]	M5 grades H (Am/g)
0.5	-130
0.6	-129.4
0.7	-129.2
1	-120
1.1	-116.5
1.3	-110.5
1.4	-96
1.5	-80
1.6	0
1.7	310
1.8	1870
1.9	9370

B-H curve data can be took from the hysteresis loop magnetizing curve of the material. Magnetizing curve for M5 grade material is obtained from the technical details of the CRGO material. Each of the limb and yokes block label need to be entering with the data such as coercive force of magnet, field source and others.

Directions of the coercive force of magnet are set to same to both of right and left limb. Only the centre limb are set different direction pole from the both right and left limb. In this drawing, the pole were set to be 90° for the right and left limb and the centre limb will be set to -90°. This will make sure flux from left and right limb will flow through the centre limb. Meanwhile for the upper yoke and lower yoke the direction were set to zero degree for both upper and lower yokes. [2]

After entering the related data for each of the block label properties, data label for edge also need to be set also. In this drawing, only air type and steel type need to be set for the edge label property. In the edge properties, for every edge of the steel need to be assign to tangential field and for the air edge, it need to be assign to magnetic potential

Before any simulation took place, the drawing should be check either mesh can produce all over the drawing or not. There is button build mesh on top of the drawing toolbar. When building mesh is finish, the drawing will be cover with green line all over the drawing.

Simulation only can be executed after mesh had been built off. To execute the simulation, there is executing button on the toolbar icon. If the simulation success without having any error on the drawing a result with flux line flow through the core will come out. Value of flux density can be obtained from the field picture by right clicking on the result drawing. To check the local value, click on local value button and just pointing mouse at any space of the simulation result to get the result value.

3. ANALYSIS

Flux Density formula:

$$B = \mu H \qquad (1)$$

$$\mu = \mu_o \mu_r \qquad (2)$$

where μ = material permeability
H = material intensity from the table

The flux density is assumed to lie in the plane of model (xy or zr), while the vector of electric current density **j** and the vector potential **A** are orthogonal to it. Only j_z and A_z in planar or j_θ and A_θ in axisymmetric case are not equal to zero. We will denote them simply j and A. Finally, the equation for planar case is

$$\frac{\partial}{\partial_x}\left(\frac{1}{\mu_y}\frac{\partial A}{\partial y}\right)+\frac{\partial}{\partial y}\left(\frac{1}{\mu_x}\frac{\partial A}{\partial y}\right)=-j+\left(\frac{\partial H_{cy}}{\partial x}-\frac{\partial H_{cx}}{\partial y}\right) \qquad (3)$$

and for axisymmetric case is

$$\frac{\partial}{\partial_r}\left(\frac{1}{r\mu_z}\frac{\partial (rA)}{\partial r}\right)+\frac{\partial}{\partial z}\left(\frac{1}{\mu_r}\frac{\partial A}{\partial z}\right)=-j+\left(\frac{\partial H_{cr}}{\partial z}-\frac{\partial H_{cz}}{\partial r}\right) \qquad (4)$$

where components of magnetic permeability tensor μ_x and μ_y (μ_z and μ_r), components of coercive force vector H_{cx} and H_{cy} (H_{cz} and H_{cr}), and current density j are constants within each block of the model.

In order to find the loss of energy per cycle or magnetization of transformer core lamination as follow.
Let I = mean of iron bar
A = its area of cross section
N = No of turns of wire of the solenoid.
with relate the B-H curve of core material shown in figure 3.

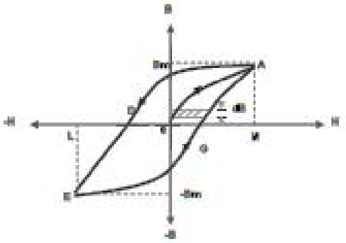

Figure 3: Hysteresis curve

If B is the flux density at any instant, then $\Phi = BA$ when current through solenoid changes, then flux also changes and so produces and induced e.m.f whose value is

$$e = N\frac{d\Phi}{dt}volt \qquad (5)$$

$$e = N\frac{d(BA)}{dt} = NA\frac{dB}{dt}volt \qquad (6)$$

Now, $H = NI/l$ or $I = Hl/N$ (7)

The power of rate of expenditure of energy is maintaining the current 'I' against induced e.m.f 'e' is

$$= eI.watt = \frac{H.l}{N}\times N.A\frac{dB}{dt} = A.l.H\frac{dB}{dt}\text{ Watt} \qquad (8)$$

Energy spent in time 'dt

$$A.l.H\frac{dB}{dt}\times dt = A.l.H.dB \quad \text{Joule}$$

Total network done for one cycle of magnetization is

$$W = A.l\oint H.dB\text{ Joule} \qquad (9)$$

Hence $\oint H.dB$ = area of the loop, i.e the area between B-H curve and the B-axis.
So, *work done, cycle = A.l x (area of the loop)* Joule
Now *A.l = volume of material*
So *net work done/cycle/m³ = (loop area)* Joule
Or W = (area of B-H loop) joule/m³/cycle

4. RESULT AND DISCUSSION

As an overview flux will flow through the core limb in various patterns. From figure 4 it shows that flux flow through centre limb from each left and right limb. Simulation using Quickfield software showing the flux lines flow through the limb and yoke of transformer core.

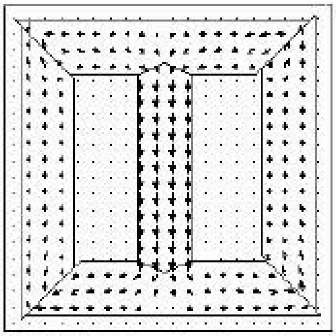

Figure 4: Flux lines flow through transformer core

The flux density value from simulation is 1.78 T as indicated in figure 5. Flux density that is flow through the transformer core is not uniform. The maximum flux density is found in the centre limb of transformer core. Because the flux density that is flow from the left and right limb of the transformer core is enter toward the centre limb of transformer core.

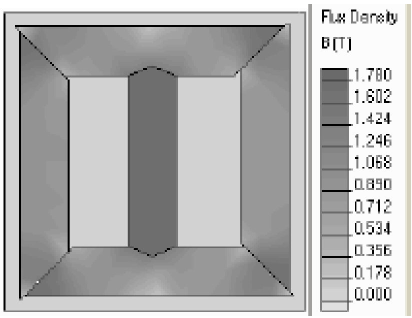

Figure 5: The flux density occur in the transformer core lamination

An energy density value is recorded in unit J/m³. For M5 grade material of the transformer core has the value of energy density is 195 J/m³. Energy density obtained from the simulation result is shown in figure 6. In this figure shows the energy density occurs at the left and right limb of transformer core.

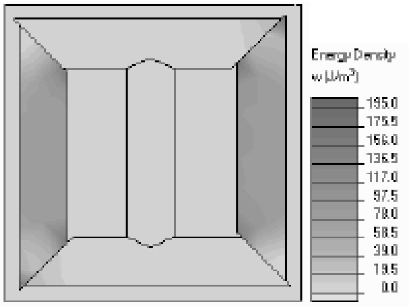

Figure 6: Energy density simulations on transformer core

From the simulation result, some data can be obtained such as;
Energy Density, ωH = 195 J/m^3
Density = 7.65kg/dm^3 (from the B-H curve)

In order to find frequency, the equation is;

$$f = \frac{1}{t} = \frac{1}{t\,\mathrm{sec}} = 50Hz \;;\; t = \frac{1}{50}\mathrm{sec}$$
$$= 0.02\,\mathrm{sec}$$

From simulation result data, power loss per kg can be calculated using;

$$Power.Loss/kg = \frac{195J/m^3}{7.65kg/dm} = \frac{195J/m^3}{7.65\times10^3kg/m^3}$$
$$= \frac{195}{7.65\times10^3}J/kg = \frac{195\times50}{7.65\times10^3}J/sec/kg \;\; = \mathbf{1.274 Watt/kg}$$

5. CONCLUSION

Loss evaluation has become important because of high energy cost. Therefore, it is necessary to know in detail the behaviours of flux in transformer in order to develop cores with higher efficiency.The values for material can be obtained from the B-H curve

From the result of simulation found the flux density is 1.78 T and the loss calculation is 1.274 W/kg. Flux density that is flow through the transformer core is not uniform. The maximum flux density is found in the centre limb of the transformer core.

REFERENCES

[1] Nakata, T., Numwrical Analysis of flux and loss distribution in Electrical Machinery (invited), *IEEE Trans. On Mag., Vol. MAG-20, no. 5* Sept. 1984.

[2] Richard C. Dorf , *The Electrical Engineering Handbook*, 2nd Edition,CRC Press, pp: 32-35 1997.

[3] I. Daut, Dina M.M. Ahmad, S. Zakaria, S. Uthman and S. Taib, Comparison of Losses and Flux Distribution in 3 phase 100kVA Distribution Transformer Assemble from Various Type of T-Joint Geometry, *American Journal of Applied Science* 3 (9):1990-1992, 2006

[4] Gunther F. Mechler, Ramsis S.Girgis Magnetic Flux Distribution in Transformer Core Joints, *IEEE Transaction on Power Delivery Vol. 15,No 1*, Jan. 2000

[5] Ismail Daut, Dina Maizana,Electrical Engineering Principle, Kolej Universiti Kejuruteraan Utara Malaysia (KUKUM) 2005.

[6] Anthony J. Moses, Bleddyn Thomas, and John E. Thomson, Power Loss and Flux Density Distributions in the T-Joint of a Three Phase Transformer Core, *IEEE Trans. On Mag., Vol. MAG-8, no. 4* Dec 1972.